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Japanese Nuclear Power and the Kyoto Agreement

Mustafa Babiker, John M. Reilly and A. Denny Ellerman

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Mustafa Babiker, John M. Reilly and A. Denny Ellerman†

Abstract

We find that, on an economic basis, nuclear power could make a substantial contribution for meeting the emissions target Japan agreed to in the Kyoto Protocol. It is unlikely however that the contribution would be as large as projected in official Japanese forecasts. The economic costs of the carbon constraint rise if siting, construction, and approval problems prevent the economically desirable level of expansion of nuclear power. We also evaluate the economic effects of subsidizing nuclear power to achieve the expansion projected in official forecasts. While the subsidy required is substantial, the economic welfare effects are relatively small because of second-best considerations. We use the EPPA model, a global computable general equilibrium model, in the analysis. Our estimates thus include the effects of changing world energy prices and terms of trade as they affect competitiveness of nuclear power and economic welfare.

Contents

1. INTRODUCTION

The Kyoto Protocol of the Framework Convention on Climate Change (FCCC) seeks to limit carbon emissions. Japan agreed to reduce 2008–2012 greenhouse gas (GHG) emission by 6% below 1990 levels (FCCC, 1998). Official Japanese forecasts foresee meeting this reduction through substantial expansion of nuclear power (MITI/ANRE, 1998a). Nuclear power is an attractive energy technology for meeting carbon dioxide restrictions because there are no direct emissions of CO_2. To be economically attractive, however, it must compete with other measures that could also reduce emissions. Apart from the tangible costs of nuclear power, there are difficulties in siting and gaining local approval for new nuclear plants. These difficulties could be a further constraint on using nuclear power as a main instrument for meeting the relatively near-term requirements of the Kyoto agreement.

We evaluate the economic implications of carbon dioxide restrictions on the Japanese economy using the MIT *E*missions *P*rediction and *P*olicy *A*nalysis Model (EPPA). We impose an economy-wide constraint on carbon emissions in EPPA to evaluate the economically efficient

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level of nuclear power expansion as a response to a carbon constraint. EPPA is a computable general equilibrium (CGE) model of the world economy. We focus on the year 2010 as representative of the 5-year period over which average emissions in Annex B countries must meet the Kyoto protocol limits. We focus particular attention on the potential contribution of nuclear power in meeting the Kyoto carbon reduction target.

There have been some other recent studies of nuclear power in Japan (*e.g.*, Kawai and Oda, 1998). A major difference of this study is that we use a global general equilibrium model. Computational requirements mean that the model has somewhat limited detail on the electric power sector. The advantage of the model is that we are able to investigate economy-wide interactions as well as international trade effects. One important effect is that simultaneously constraining carbon emissions in all Annex B countries leads to a significant fall in the price of oil, an internationally traded good. The fall in the price of oil affects the relative economics of nuclear versus fossil generated electric power. Broader trade effects include changes in the terms of trade of Japan (the price of its exports relative to its imports). The CGE model also allows us to compute several different measures of economic impact including the effect on GNP, on welfare in terms of equivalent variation, and on the shadow price associated with the carbon constraint.[1] EPPA does not model economic damages due to climate change and, as a result, does not capture any welfare benefits (reductions in damages) due to the carbon constraint. Thus, our analysis should be considered a cost-effectiveness analysis.

We provide a more complete description of the model in Section 2, a description of our reference case and how we constructed policy and sensitivity cases in Section 3, the results of the model simulations in Section 4, and our major conclusions in Section 5.

2. THE EPPA-GTAP MODEL

EPPA has been designed to analyze climate change policy and has been used extensively for this purpose (Yang *et al*., 1996; Jacoby *et al*., 1997). While the overall framework of EPPA-GTAP is similar to previous versions, it includes several significant revisions. Among the most significant changes for the analysis presented here were updating the model to use the GTAP data, changes in the resource component of the model, and modeling of nuclear power as a separate electricity generation technology. These latter changes are particularly relevant to the assessment of nuclear power because they affect comparative costs of nuclear and fossil fuel generated electricity.

2.1 Model Description

The EPPA model is a recursive dynamic multi-regional general equilibrium model of the world economy. The current version of EPPA is built on a comprehensive energy-economy data set (GTAP-E[2]) that accommodates a consistent representation of energy markets in physical units

[1] We consider only emissions through 2010. We also consider only carbon emissions abatement options. Reilly *et al*. (1999) studies a multigas abatement policy that more closely parallels the Kyoto protocol. In that analysis, consideration of other gases and sinks reduced the shadow price of carbon by about 12% for Japan, compared to the case where only CO_2 was included.

[2] This special database is provided by the Global Trade Analysis Project (GTAP) along with release four of their economy-trade database. For further information on GTAP see Hertel (1997).

as well as detailed accounts of regional production and bilateral trade flows. The base year for the model is 1995 and the model is solved recursively through 2100 at 5-year intervals. There are three commodity groupings and 12 regions in EPPA. Description of the specific regions and commodities included in the model is provided on **Table 1**.

Nested CES functions are used to describe technologies and preferences. **Figure 1** illustrates the nesting structure employed for production sectors and **Figure 2** shows that for the final demand sector. The model default substitution elasticities are reported in **Table 2**.

The model's equilibrium framework is based on final demands for goods and services in each region arising from a representative agent. Final demands are subject to an income balance constraint with fixed marginal propensity to save. Investment is saving driven and capital is accumulated subject to vintaging and depreciation. Consumption within each region is financed from factor income and taxes. Taxes apply to energy demand, factor income and international trade, and these finance an exogenously grown level of public provision. Capital flows in base year accounts are phased out gradually and the government budget is balanced each period through lump-sum taxes.

Along the baseline, fossil energy resources are calibrated to an exogenous price path for fuels through 2010, and afterwards they are driven by a long-run resource depletion module. Energy goods and other commodities are traded in world markets. Crude oil is imported and exported as a homogeneous product, subject to tariffs and export taxes.

Figure 1. Production Structure

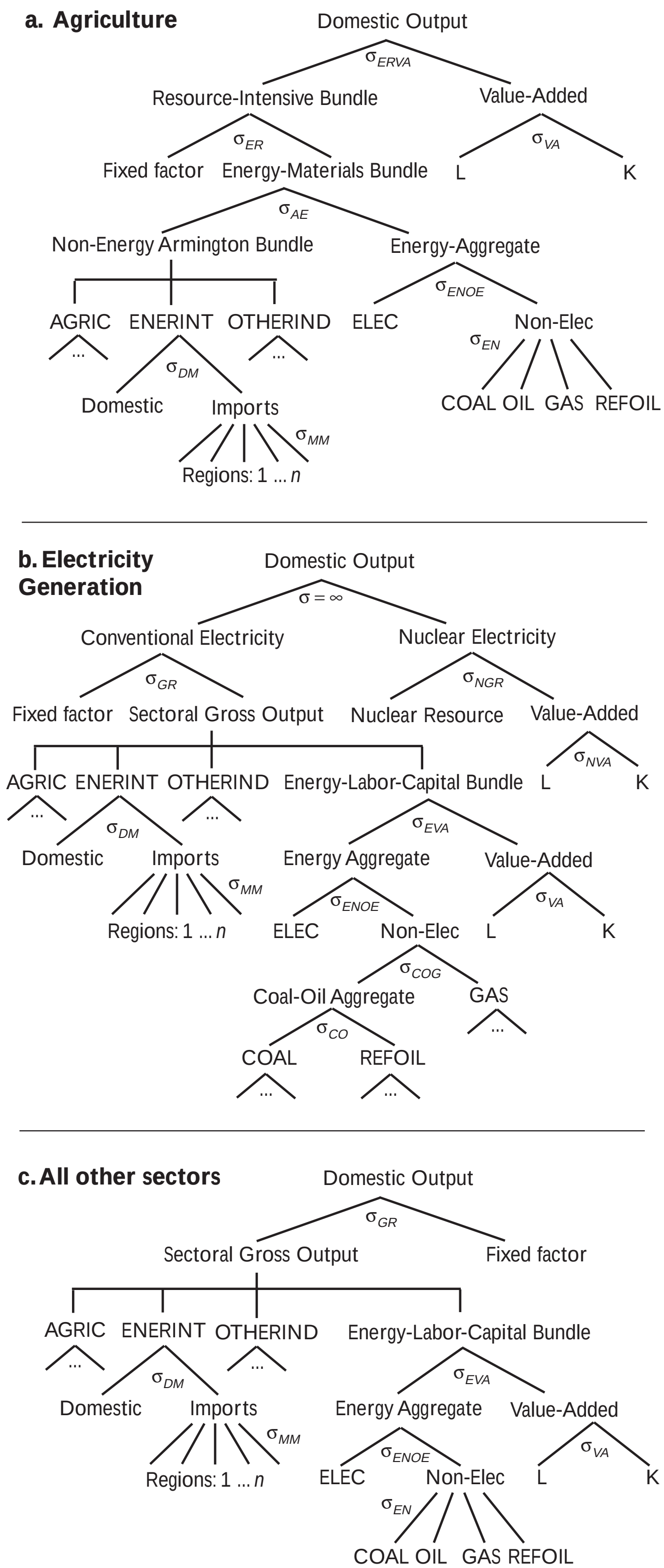

Table 1. Countries, Regions, and Sectors in the General Equilibrium Model

Country or Region		Commodities	
USA	United States	AGRIC	Agriculture
JPN	Japan	COAL	Coal
EEC	Europe	OIL	Crude Oil
OOE	Other OECD[†] Countries	GAS	Natural Gas
FSU	Former Soviet Union	REFOIL	Refined Oil
EET	East European Associates	ELEC	Electricity
IND	India	ENERINT	Energy Intensive products
BRA	Brazil	OTHERIND	Other Industries products
CHN	China (including Hong Kong & Taiwan)		
EEX	Energy Exporting Economies		
DAE	Dynamic Asian Economies		
ROW	Rest of world		

[†] OECD = Organization for Economic Cooperation and Development. OECD countries: Western Europe, the United States, Canada, Australia, New Zealand, and Japan, plus countries of Eastern Europe and the former Soviet Union, as listed in the Kyoto Protocol.

Table 2. The Model Default Parameters

Parameter	Description	Value	Comments
σ_{ERVA}	Elasticity of substitution between energy resource composite and value-added	0.6	Agriculture only
σ_{ER}	Substitution between land and energy-material bundle	0.6	Agriculture
σ_{AE}	Substitution between energy and material composite	0.3	Agriculture
σ_{VA}	Substitution between labor & capital	1	All sectors except nuclear in which is 0.5
σ_{ENOE}	Substitiution between electric and non electric energy	0.5	All sectors
σ_{EN}	Substitution among non-electric energy	1	All sectors except for electricity where coal and oil generation substitute at 0.3 among themselves and at 1 with gas
σ_{GR}	Substitution between fixed factor and the rest of inputs	0.6	All sectors that have fixed resource, except nuclear generation where it is calibrated to match exogenous supply elasticity
σ_{EVA}	Substitution between energy and value added composite	0.4	For all sectors except energy intensive and other industry where it is 0.5
σ_{DM}	Armington substitution between domestic and imports	3	All goods except Electricity where it is 0.3
σ_{MM}	Armington substitution across imports	5 4	Non-energy goods Energy goods, except refined oil (6) and electricity (0.5)
σ_{CS}	Temporal substitution between consumption and saving	1	Final demand sector
σ_{C}	Substitution across consumption goods		Varies across countries and is updated with income recursively to reflect income elasticities based on an econometrically estimated equation
G0	Labor supply annual growth rate in efficiency units	2% 2.5-6%	For developed countries and converges to 1 by 2100 For developing countries and converges to 1.5% by 2100

All other goods, including energy products such as coal and natural gas, are characterized by product differentiation with an explicit representation of bilateral trade flows calibrated to the reference year, 1995.

Energy products (refined oil, coal, natural gas, and electricity) are sold at different prices to industrial customers and final consumers. All existing energy subsidies are phased out gradually along the baseline.

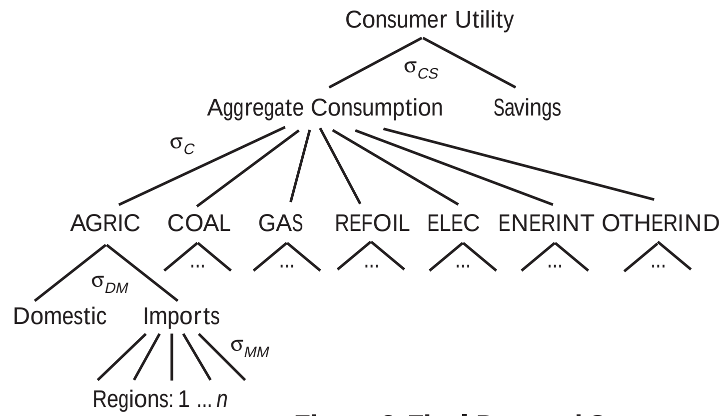

Figure 2. Final Demand Structure

2.2 Nuclear Power Costs and Energy Prices

The GTAP data does not provide a separate sectoral breakdown for each electric generation technology. To develop an estimate of nuclear electricity output consistent with the GTAP data, we applied the nuclear output share of electricity production for each EPPA region, based on International Energy Agency data, to divide the total output of the electric sector in GTAP into two components, nuclear and non-nuclear. To estimate input requirements for different types of power generation we used data from on a joint study of the Nuclear Energy Agency and the International Energy Agency (NEA/IEA, 1998) on comparative costs of different generation technologies.

As noted above, we specify energy prices exogenously in the reference case through 2010 after which the price path is determined by a resource model. The implication of setting prices exogenously is that the quantities of the resources available are endogenously determined. These reference-case quantities are then used in cases under policy constraint, so that energy prices respond endogenously to the policy shocks. This approach provides the flexibility to consider the implications of different assumptions about the price path of energy in the near term, independent of longer-term resource considerations. For example, the exogenous price path can be interpreted as a gradual reestablishment of long-term equilibrium conditions from a disequilibrium state in the base year. Or, it can reflect changes in monopoly power and associated monopoly rents that lead to a change in the value of the resource. In constructing our reference case we noted that energy prices had declined on the order of 25 to 30% between 1995 (the base year) and 1998. There has since been some recovery in oil prices but many expect that energy prices may remain below the 1995 level for some time. We imposed gradual price declines in all energy prices from 1995 through 2010. This implies some recovery from 1998 lows.

3. POLICY STUDIES

Most economic variables such as GDP growth, energy prices, wages, and other variables are endogenously determined within the model reflecting the choice of parameter values as described in Section 2. The standard approach for simulating the impacts of a policy change in a computable general equilibrium model is to generate a reference scenario, impose a policy, and compare the economic effects between the reference and policy cases.

3.1 Measures of Policy Costs

We compare the economic effects of policies in terms of economic welfare (equivalent variation), Gross National Product (GNP), and the shadow price of the carbon constraint. These measures have somewhat different interpretations. The reference solution to a general equilibrium model is generated such that resources available to the economy are used in the most efficient manner given the reference technology and policy constraints. As a result, any new intervention (such as a carbon constraint) will cause the economy to use resources less efficiently. Such an intervention will, as a result, generally lead to a reduction in economic welfare compared with the reference case.[3] Economic welfare, measured as equivalent variation, is the amount of income consumers would need to compensate them for the welfare losses due to the policy.

GNP is measure of the productive capacity of the economy. A change in economic welfare is a more comprehensive measure of the impact on the economy, because it includes both the change in output (GNP) and the change in consumer prices. Constraining the economy to use resources less efficiently will tend to reduce output of goods and services and, consequently, reduce GNP, consumption and welfare. Consumer price changes also depend on changes in the terms of trade (the relative price of exported versus imported goods). The terms-of-trade effect depends both on what happens to other Annex B regions that are sources of Japanese imports and to the cost of Japanese export goods. These terms-of-trade changes affect the calculation of welfare, but not directly affect GNP.

The shadow price of carbon is the cost to the economy of controlling the last ton of carbon needed to meet the constraint, whereas both welfare and GNP impacts are estimates of the total cost of a policy constraint. The shadow price of carbon is the Lagrangian multiplier associated with a carbon constraint imposed on producers (including household production) computed as part of the economic optimization problem. In other work with EPPA we have simulated the shadow price of carbon under a set of different carbon policies to generate a Marginal Abatement Curve (MAC) that relates the reduction in emissions from reference to the shadow price (Ellerman and Decaux, 1998).

3.2 Policy Cases and Sensitivities

We evaluate several policy and sensitivity cases as summarized in **Table 3**. We evaluate the likely growth in nuclear power in a reference case without the Kyoto agreement. We then constrain the model so that Annex B countries including Japan individually meet the agreed targets set out in the Kyoto Protocol. We include the Kyoto constraint for all regions in Annex B because doing so has implications for the changes in terms of trade.[4] We compare nuclear power growth in the constrained case to that in the reference case, and to MITI forecasts of nuclear power growth. In these cases, nuclear power competes on the basis of comparative economics with fossil generated electricity.

We consider additional cases where nuclear power expansion is prescribed at levels other than those predicted by EPPA, which are based on pure economic considerations. These include a

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[3] If there are pre-existing distortions a policy intervention can generate economic welfare benefits, if it is a correction to the original distortion.

[4] See, Babiker and Jacoby (1999) for a description of the implications of implementing the Kyoto agreement for other regions.

constrained nuclear power case where, by 2010, only those plants now under construction or commissioning are completed. There is currently one nuclear power plant under construction with a capacity of 825 MW and four plants under commissioning with a combined capacity of 4,663 MW. There are currently 51 plants in operation with a combined capacity of 44,917 MW so these additions would represent a 12% increase in generating capacity.[5] This case represents the prospect that getting local approval for additional nuclear power plants may be a constraint on further expansion, at least in the 2008–2012 time period. The evidence from nuclear power plants completed over the past two decades illustrates the difficulty that can be encountered in planning and constructing plants. Five power plants were brought on line in Japan in the 1980s. The time required to complete these plants, from initial planning to operation, averaged 17.4 years. The single plant brought on line in the 1990s required 25.7 years (MITI/ANRE, 1998b).

To further investigate the economic implications of moving forward with a more rapid nuclear power plant construction program, we also prescribe nuclear power expansion at the level projected by the Ministry of International Trade and Industry (**Table 4**). The basic elements of

Table 3. Policy and Sensitivity Cases

Constraint/ Sensitivity	Case	Value	Comments
GNP growth, %/yr, 1995-2010	Reference GNP: High GNP:	1.5 2.3	The High GNP growth corresponds to the MITI/ANRE (1998a) GNP forecasted growth over the period.
Carbon constraint, 2010, MtC	Kyoto Policy	1103	Calculated to be 94% of 1173 MtC emitted in 1990. All Annex B regions constrained to meet Kyoto commitment as in FCCC (1998).
Energy Prices, %/yr change, 1995-2010	Prices Ref. Oil: -1.6 Gas: -0.1 Coal: 0	High +1 +1 +1	Reference (Ref.) levels assume that energy prices through 2010 are in the range observed between 1995 and 1998. Oil is modeled as a Hecksher-Ohlin good with a common world price. Coal and gas are modeled as Armington goods. Price changes reported are domestic price changes in Japan.
Nuclear, % increase, 1995-2010	High Nuclear Low Nuclear	65 12	The high case corresponds to the MITI projection. The low case corresponds to the addition of the 5 units either under construction or commissioning.

Table 4. MITI Electricity Sector Forecasts, GWh

	1995		1996		2010	
	GWh	%	GWh	%	GWh	%
Coal	118,100	14	123,700	14	136,000	13
Oil	157,100	18	154,700	18	87,000	8
Gas	219,800	25	203,700	23	213,000	20
Nuclear	291,100	33	302,100	35	480,000	45
Hydro	86,000	10	83,800	10	119,000	11
Geothermal	3,100	0	3,600	0	12,000	1
Renewable	1,200	0	1,300	0	9,000	1
Total	876,400	100	872,900	100	1,056,000	100

Sources: Data for 1995 are from MITI/ANRE (1997); Data for 1996 and projections for 2010 are from MITI/ANRE (1998a).

[5] By constraining production increases at this 12% level we assume no further increase in the capacity utilization factor. Since the 1970s when capacity utilization factor was on the order of 50%, Japan's average capacity factor has risen to just over 80% (MITI/ANARE, 1998b).

the forecast include an increase in the share of power produced by nuclear from 33 to 45%, while electricity production increases by 20% between 1995 and 2010. The increased share of nuclear requires an increase in nuclear generated electricity of 65% with absolute reductions in generation of oil, gas and coal combined between 2000 and 2010 of nearly 20%. Oil generated power sees the largest decline, 45% between 1995 and 2010. For nuclear to expand at this rate thus requires that the levelized cost of a new nuclear power plant be less than the fuel cost alone of gas, oil, and coal generated electricity since the capacity to generate electricity with these fuels already exists. The subsidy required to meet this target is endogenously computed in the EPPA model.

We also consider the sensitivity of our results to the rate of GNP growth and fossil energy prices because future carbon emissions and the costs of meeting a carbon constraint depend on these factors. To test the sensitivity of results to GNP growth we increased the labor efficiency parameter to generate a High GNP growth case. The High GNP growth case (2.3% per year) was chosen to be identical to the MITI/ANRE (1998a) forecast to facilitate comparison of our model results with the MITI forecasts for electricity and nuclear power production. Faster economic growth generates higher emissions in the reference case and requires larger reductions in emissions when compared with the reference GNP growth case. The Marginal Abatement Curve (MAC) in **Figure 3** illustrates how the shadow price of carbon and total costs of abatement is highly dependent on the required reduction and also compares the MAC for Japan with other Annex B regions.[6] The marginal abatement curve for Japan rises steeply so that the carbon price

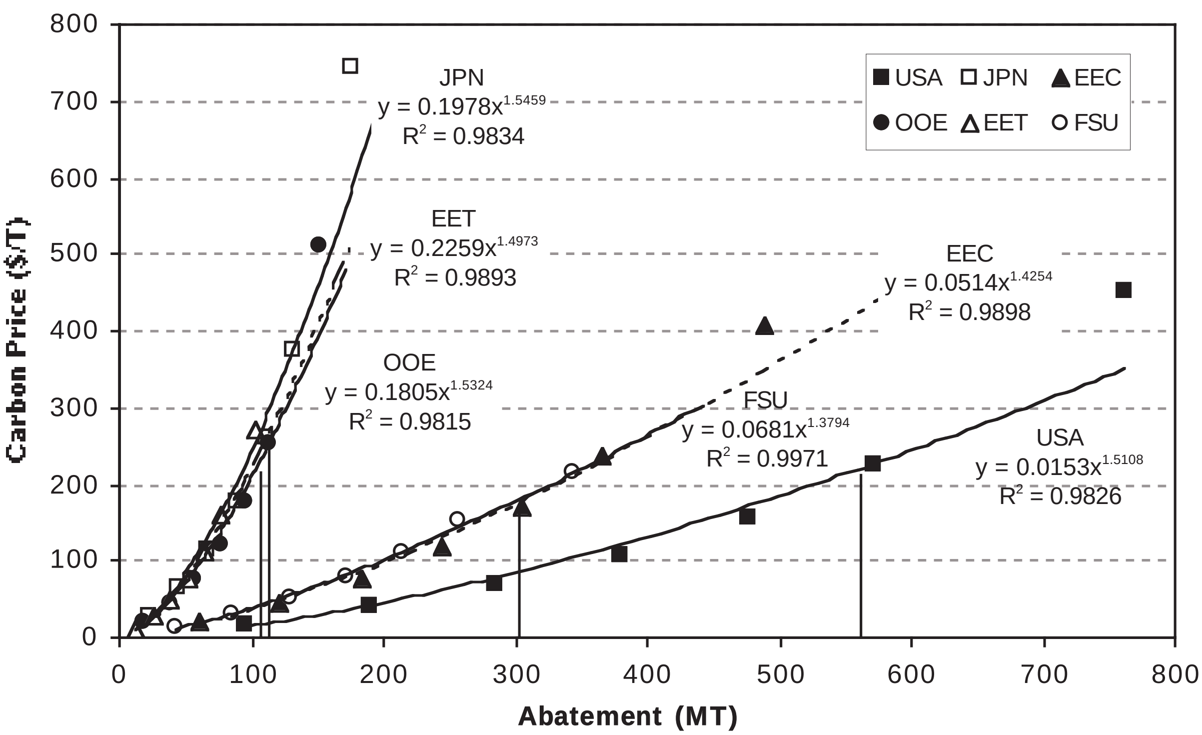

Figure 3. EPPA GTAP/IEA (version 3.0) Annex B Marginal Abatement Curves (2010, No Trading)

[6] The MAC in Figure 3 was constructed as in Ellerman and Decaux (1998) using output from the version of the model described herein.

is much higher if GNP and consequently carbon emissions grow more rapidly. As a summary of the complex EPPA model, the MAC can be used to indicate what the approximate effects on the carbon price will be with different required reductions.

As discussed previously, in the reference case fossil energy prices were prescribed to fall between 1995 and 2010. We include a sensitivity case where, instead, oil, coal, and gas prices rise by 1.0% per year in Japan and similarly worldwide. Over the past four or five years world oil prices have ranged from around $18 per barrel to as low as $12 barrel, illustrative of the uncertainty in fossil energy prices.

4. RESULTS

The largest differences in the impact of the Kyoto protocol occurs between those scenarios with Reference and the High GNP growth (**Table 5**). By construction, growth in the economy and hence welfare is much higher in the high GNP case. As energy use and carbon emissions are closely tied to economic growth we find, as a result, that the carbon price (in 1995 $US) is nearly $200 per ton higher ($461 compared with $269) in the High GNP case. Loss in welfare due to the carbon constraint in the reference GNP case is 0.9% in the year 2010 but is 1.9% in the high GNP case reflecting the steeply rising marginal costs associated with making larger emissions reductions. The GNP losses are generally larger (1.5 and 2.5% in the Reference and High GNP growth cases, respectively) than the losses in welfare. This can be traced to the terms-of-trade effects (Babiker and Jacoby, 1999). A significant part of this terms-of-trade effect is that carbon constraints imposed in the Annex B countries reduce world energy prices. Lower energy prices improve the terms of trade for energy importers such as Japan while energy exporters suffer deterioration in their terms of trade. This terms-of-trade improvement is the main reason why the welfare cost is less than the fall in GNP.

Table 5: Japan, Nuclear Power, and Kyoto

	Percentage Change, 1995-2010				**1995 $US**
	GNP	**Welfare**	**Nuclear**	**Electricity**	**Carbon Price**
Reference	25.1	27.4	6	15	*n.a.*
with Kyoto	23.6	26.5	24	8	269
12% nuclear growth[†]	23.4	26.3	12	7.5	289
65% nuclear growth*	23.7	26.4	65	9.4	197
High GNP growth	40.4	43.7	6	26	*n.a.*
with Kyoto	37.5	41.8	32	14	461
12% nuclear growth	37.1	41.5	12	13.6	505
65% nuclear growth	37.6	41.8	65	16	382
Reference, high energy price	24.3	26.7	9	13	*n.a.*
with Kyoto	23.3	26.1	23	8	209
High GNP, high energy price	39.5	42.9	9	24	*n.a.*
with Kyoto	37.2	41.5	31	15	391

[†] In the 12% nuclear cases the quota constraint is on nuclear fuel and the percentage refers to percentage reduction in the nuclear fuel resource.

* In the 65% nuclear cases, nuclear production is subsidized and the subsidy percentage is on the total cost of nuclear production.

n.a. = not applicable

Electricity growth is also closely related to GNP growth. It grows 15% between 1995 and 2010 in our reference case but 26% in the High GNP case. Nuclear power growth is, however, not influenced by economic growth in these cases. This result can be traced to the fact that low fossil fuel prices in these two cases provide little incentive to expand nuclear. The 6% increase in nuclear power production simulated in these cases could be achieved by completing just two plants (*e.g.*, the one plant under construction plus only one of the four plants under commissioning).

If Japan meets the Kyoto target with an economically efficient, economy-wide instrument such as a carbon tax or a tradable permit system our simulations suggest a much wider economic role for nuclear power. In the High GNP growth case nuclear power expansion is 32%. This is, however, only about one-half the increase projected in the MITI forecast. One reason is that the carbon constraint reduces GNP by 3%. More importantly, electricity use is significantly curtailed (a 14% increase instead of 26%). In the MITI forecast electricity growth is just over 20% (Table 3). In the reference GNP case with the Kyoto constraint electricity growth is only 8%. One important conclusion is that our simulations see a far greater response in electricity use as a result of an efficient economy-wide carbon control policy than in the MITI forecast. This comes about in our model because rising costs of electricity generation is passed on to consumers as higher prices, damping demand growth.

While these simulations show less nuclear power growth than the MITI forecast, they still project a substantial nuclear power plant construction program. In the High GNP case approximately twelve new power plants (on the order of 1200 MW each) would be required; that is, seven more beyond the five already under construction or commissioning. In the Reference GNP case, nine new power plants would be required, four more beyond the five already under construction or commissioning. This is in contrast to the total of twenty-two new plants (including the one plant under construction plus the four under commissioning) in the MITI forecast.

When we prescribe nuclear power expansion at the level projected by MITI we find the need for significant subsidies for nuclear power. To achieve the 65% increase in nuclear power production in our scenarios requires a subsidy in the reference GNP case equal to 67% of the cost of nuclear power production. In the High GNP case the subsidy must equal 53% of the cost of nuclear power.[7]

When we constrain nuclear power expansion to a 12% increase from 1995, electricity consumption is reduced somewhat due to higher prices and GDP and welfare declines, compared with the cases where only the carbon constraint is implemented. The shadow price of carbon increases by about $20 per ton in the Reference GNP case and $40 per ton in the High GNP case. The shadow price rises because other parts of the economy must reduce carbon emissions further. The effect when nuclear power is subsidized is to reduce the shadow price of carbon by $70 to $80 per ton. The shadow price falls in these cases because the subsidization of nuclear lessens the need to reduce carbon elsewhere in the economy. Electricity consumption increases in this case because the subsidy of nuclear reduces electricity prices to consumers.

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[7] A subsidy of nuclear power production is one mechanism that could be used to force this expansion. Other mechanisms such as taxes on other generation modes, or forced retirement of them, would have somewhat different implications for consumers and the economy.

While the effects on the shadow price of carbon in the nuclear constrained and subsidy cases are in opposite directions, both show additional loses in economic welfare from the case where the Kyoto target is achieved with an economy-wide carbon constraint. The difference is, however, less than 0.1% of welfare in the High GNP growth case compared with the welfare loss of 0.3% for the constrained nuclear case.[8] The constrained case involves a 20% lower increase in nuclear in the high GNP case, whereas the subsidy case requires an additional 33% expansion of nuclear. This asymmetric effect can be traced to the fact that there are large excise taxes on electricity production in Japan. These taxes amount to a pre-existing distortion. The nuclear production subsidy, by decreasing electricity prices, partially offsets the effect on welfare of taxes that raise prices to consumers. The nuclear power subsidy is not a true “second best” policy. It creates additional welfare losses whereas a second-best policy would improve welfare but not as much as the “first best” policy of removing the distortionary taxes. Nevertheless, the pre-existing taxes make the nuclear subsidy case relatively less costly in welfare terms than it would be without the taxes.

In the sensitivity exercise (with fossil prices rising by 1.0% per year from 1995 to 2010) the reference cases (without the carbon constraint) exhibit losses in welfare and GNP compared with the same calculation under reference energy price cases. This result is fully expected. Higher fossil energy prices are clearly a burden on an economy that must import energy. Electricity growth is also slower. Nuclear power production expands more (9% as compared with 6%). In the carbon constrained cases, the carbon price is lower and nuclear power expansion is somewhat less than in the comparable cases with the reference energy prices. This reflects the fact that higher fossil energy prices already reduce carbon emissions throughout the economy, with less need to expand nuclear power.

5. SUMMARY

The rate of economic growth through 2010 is the largest source of difference in estimates of the cost to the Japanese economy of meeting the Kyoto Protocol. With GNP growth of 1.5% per year, we estimate the annual cost of the Kyoto Protocol in 2010 to be 0.9% of total welfare compared with welfare in the reference GNP growth case. The cost in terms of welfare rises to 1.9% with economic growth of 2.3% per year compared with welfare in high GNP growth case. Clearly, however, the average Japanese consumer is far better off with higher economic growth even if (s)he must bear a higher cost of Kyoto. With high GNP growth, economic welfare is more than 50% higher in 2010 than in the reference GNP growth, with or without Kyoto, and across the measures we examined to implement Kyoto.

A recent MITI forecast included economic growth of 2.3% per year and anticipated a 65% expansion of nuclear power production to meet the Kyoto target. Our model results project a much less rapid expansion of nuclear power. To achieve a 65% increase in nuclear power would require large subsidies (we estimate 50–70% of the cost of nuclear power production) or other policy measures. Such expansion would also require rapid local approval for new nuclear power plants and commissioning of these plants for operation. Attempting to meet Kyoto with this rapid nuclear expansion would be more costly in terms of welfare than applying uniform carbon tax or

[8] The difference is indistinguishable when rounded to the nearest tenth of a percent as in Table 5.

implementing a cap and trade system. The extra welfare cost in the subsidy case is quite small, however, because of pre-existing distortions in the electricity market that raise the price of electricity to consumers. The nuclear subsidy, by lowering the cost of electricity, partly offsets the welfare losses from the pre-existing distortions.

While we do not estimate a nuclear power expansion as rapid as in the MITI forecast, we still see a substantial role for nuclear power if Japan is to meet the Kyoto constraint in the most cost-effective manner. In our Kyoto policy cases, nuclear power increases between 23 and 34% depending on economic growth and energy prices. This rate of expansion would require an additional 4 to 7 new 1200 MW power plants beyond the 5 already under construction or commissioning. Given the lengthy process of approval and construction in recent decades (stretching from 17 to over 25 years), achieving even this rate of expansion may be difficult. But failure to site and approve these plants could increase the shadow price of carbon by $20 to $40 per ton of carbon.

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